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A DELAYED-NEUTRON MONITOR FOR A LIQUID-WASTE STREAM WITH HIGH GAMMA-RAY INTENSITY

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ABSTRACT

An instrument has been built to monitor the uranium concentration in a liquid-waste stream to avoid a criticality accident in a downstream holding tank. The measurement technique is based on the production and counting of delayed neutrons using the "shuffler" process because the waste contains enough fission products to produce a gamma-ray dose rate of 10 R/h on the surface of the assay tank.

The design goal was a sensitivity of 0.034 g/L (1σ = 10%) in 100 s as the stream flows at 80 L/h through the assay chamber. The instrument is to run unattended for at least three months; during this time it is to transmit assay results to the plant computer and generate warnings and alarms when necessary.

I. THE MEASUREMENT PROBLEM AND TECHNIQUE

The uranium concentration in a raffinate line is to be continuously monitored to avoid a criticality accident in a holding tank. The intensity of the ^{235}U gamma-ray emission is much weaker than that from fission products (producing 10 R/h on the surface of the assay chamber), and the rate of spontaneously emitted neutrons is too small for useful assays. The measurement technique is thus based on producing and counting delayed neutrons through the "shuffler" process.[1-4]

A ^{252}Cf source is shuffled between a storage shield and the assay chamber. The source irradiates the liquid in the assay chamber, and is retracted into the shield. Delayed neutrons are then counted. Repeating this process a few times generates enough neutron counts to reach the desired measurement precision.

The design goal was a sensitivity of 0.034 g/L (1σ = 10%) in 100 s as the stream flows at 80 (±20) L/h through the assay chamber. The instrument is to run unattended for at least three months; during this time it is to transmit assay results to the plant's computer and generate warnings and alarms according to the assay results.

II. THE INSTRUMENT

A 2-L assay chamber, mounted on the wall of a hot cell, forms part of the raffinate line. The chamber is a cylindrical annulus, so the ^{252}Cf is centered in the annulus during irradiation to minimize the size of the source. Variations in the flow rate have a small effect on the assay; accuracy is improved by taking the flow rate into account.

The ^{3}He detector tubes and amplifiers must be in the hot cell around the assay chamber, but the rest of the hardware is in the corridor outside the hot cell where maintenance is simple. To enhance the reliability of the equipment in the hot cell, the detectors are grouped into banks, each with its own voltage supply and amplifier. Should a problem be detected in a bank, it can be turned off until it becomes possible to enter the hot cell and replace it.

The normal concentration is below the sensitivity of the instrument, so the expected normal assay value is zero. To check that the instrument is working properly, a sample of ^{235}U is periodically driven into the center region of the annular chamber; an assay with this sample present is compared to a previously determined standard value.

Stepping motors drive cables attached to the ^{252}Cf source and ^{235}U sample. These materials are stored in a plug through the concrete wall connecting the hot cell with the corridor.

The instrument is controlled by a computer. The user may change the parameters of the various operations with a software option. When told to perform continuous assays, the computer sends commands to move the ^{252}Cf source

and the ^{235}U sample, start and stop timers and counters, and read counter registers. The computer displays the most recent results and trends on its video monitor while archiving data on its hard disk, transmitting the assay results to the plant computer, and closing warning or alarm relays when appropriate.

The computer corrects the delayed-neutron counts for the decay of the ^{252}Cf source, the neutron background, the raffinate flow rate, and small variations in the irradiating flux and irradiation or counting times. The result is converted into a ^{235}U concentration through a calibration curve.

A low-precision concentration is computed after every individual shuffle of the ^{252}Cf source (that is, about every 20 s); if this result is above 0.5 g/L, an alarm is generated. After five such shuffles, a more refined assay is completed with the desired precision by combining all the counts. If the result is less than 0.02 g/L, no warning or alarm is given. If the result is between 0.02 and 0.034 g/L, a warning is issued. An assay greater than 0.034 g/L warrants an alarm. These key concentrations can be quickly changed through the software by a user with a proper password.

The instrument can detect some important malfunctions and alert operators to the problems. After every shuffle, the counts in the detector banks are compared to an expected ratio; if the measured ratio is sufficiently different from the expected ratio, a malfunction is suspected. If the flux monitors do not count an expected number of neutrons during the irradiation time interval, either the monitors are malfunctioning or the ^{252}Cf source is not being positioned properly. Background counts are taken periodically. If a count exceeds a preset limit, the equipment or the separation process could be malfunctioning. If the assay with the ^{235}U sample present is insufficiently close to an expected value, an alarm is sent.

III. PRELIMINARY RESULTS

The instrument and a test flow loop have measured nitric acid solutions of ^{235}U of known concentrations. Final testing and calibration will be done after installation.

The optimum performance of the instrument was found by using irradiation times of 11 s and delayed-neutron count times of 7 s for each shuffle. A total of five such shuffles constitutes a 100-s assay.

The effect of the liquid flow rate through the assay chamber on the irradiation and counting processes cannot be ignored. The nominal flow rate of 80 L/h reduces the count rate to about 87% of a static solution's count rate. With a change of ±20 L/h from the 80 L/h, the count rate changes by about 3%.

The precision of a measurement depends on the number of delayed neutrons counted, the background count rate, the precisions of the various corrections to the count rate, and the precision of the parameters in the calibration curve. The assay precision cannot be known until after installation, but it appears that the design goal of 10% in 100 s with 0.034 g/L will be achieved.

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